IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:
DENYER ET AL.

Serial No. **09/891,134**

Confirmation No: **8833**

Filing Date: **JUNE 25, 2001**

For: **IMAGE SENSORS WITH MULTIPLE INTEGRATION/READ CYCLES**

TRANSMITTAL OF CERTIFIED PRIORITY DOCUMENT

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Sir:

Transmitted herewith is a certified copy of the priority United Kingdom Application No. 0015685.1.

Respectfully submitted,

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[ADP No. 07460272004]

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1/77

28JUN00 E548318-3 D02884
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1. Your reference — P26169/TCO/JCO

2. Patent application number *(The Patent Office will fill in this part)* — **0015685.1** — 28 JUN 2000

3. Full name, address and postcode of the or of each applicant *(underline all surnames)* — VLSI Vision Ltd, Aviation House, 31 Pinkhill, EDINBURGH, EH12 7BF

   SECTION 30 (1977 ACT) APPLICATION FILED 16/03/01

   Patents ADP number *(if you know it)* — 07787930001

   If the applicant is a corporate body, give the country/state of its incorporation — United Kingdom

4. Title of the invention — "Image Sensors with Multiple Integration/ Read Cycle"

5. Name of your agent *(if you have one)* — Murgitroyd & Company

   "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)* — 373 Scotland Street, GLASGOW, G5 8QA

   Patents ADP number *(if you know it)* — 1198013 VSA

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
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11.

I/We request the grant of a patent on the basis of this application.

Signature Murgitroyd & Company — Date 27 June 2000

12. Name and daytime telephone number of person to contact in the United Kingdom — JOHN COOPER 0141 307 8400

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Image Sensors with Multiple Integration/Read Cycles

The present invention relates to solid state image sensors. More particularly, the invention relates to CMOS-type image sensors in which multiple integration and read cycles are performed between resetting of the sensor pixels. This provides the basis for obtaining images which are low in noise and/or having a relatively wide dynamic range and/or which are resistant to flicker induced by mains frequency flickering of artificial light sources.

Solid state image sensors fabricated using CMOS technology provide a low cost imaging solution, as compared with CCD image sensors, for applications such as digital still cameras, camcorders, web cameras etc. Many kinds of CMOS imaging circuit architectures are possible, including three main types as illustrated in Fig. 1: (a) passive pixel

type; (b) 3-transistor active pixel type; and (c) 4-transistor active pixel type.

A disadvantage of types (a) and (b) above is what is known as "reset noise". This type of noise makes the reset potential of the photodiode forming part of each pixel circuit uncertain, and this uncertainty adds to pixel-to-pixel and frame-to-frame variable noise in both still and video images.

The rms magnitude of this reset noise is known to be:

$$N_{rst} = \sqrt{(kT/C)} \text{ volts}$$

Where k is Boltzmann's constant, T is absolute temperature in Kelvin, and C is the capacitance of the node being reset.

Pixel type (c) above does not suffer from this type of effect if a special type of buried diode is employed which enables the reset node to be entirely depleted of free charge. Photodiode arrays of this type ("pinned" photodiode arrays) require at least one manufacturing process step in addition to the normal CMOS process, and incur an overhead cost of at least one additional transistor per pixel as compared with a 3-transistor active pixel.

CMOS image sensors may also suffer a performance disadvantage in environments which are lit by artificial light sources whose intensity varies

rapidly in time with the AC mains supply frequency, or at some harmonic of this frequency. For example, fluorescent lights "flicker" at twice the supply the frequency. In these conditions the exposure mode of most un-shuttered CMOS sensors causes horizontal banding interference in the image, which may also be seen to scroll vertically.

It is known to correct this flicker effect by making the exposure time substantially equal to one period of the flickering source, or an integer multiple thereof.

A third disadvantage, which is common to most image sensors, is that the range of scene luminances that can be captured in one frame (i.e. the dynamic range of the sensor) is significantly limited. In practice, certain noise mechanisms limit the lowest luminance levels, and combinations of supply voltage and circuit design cause areas of the scene which are above a critical luminance to be clipped or saturated. Typically, the dynamic range available in one frame is limited to about 60 dB, but most real scenes contain luminance ranges greater than this.

The present invention relates to image sensors having modes of operation in which the operation and timing of certain active pixel sensor arrays substantially eliminates the effects of reset and flicker noise, whilst also expanding the available instantaneous dynamic range.

The invention may be applied to any active pixel architecture which supports a non-destructive read of pixel values; e.g. type (b) 3-transistor types as discussed above, but not type (a) passive pixels. The invention exploits the fact that, with pixel types which support non-destructive read operations, it becomes possible to perform multiple, staggered read operations without the pixels being re-set between read operations, so that the data read at any particular point in time represents the cumulative signal integrated up to that point since the last time the pixels were re-set.

The invention is particularly intended for use with CMOS type image sensors, image sensor systems and cameras.

In accordance with a first aspect of the invention, there is provided a method of operating a solid state image sensor having an image sensing array comprising a plurality of active pixels, the method comprising:

resetting each said pixel;

after a first predetermined period of time reading a first output from each said pixel so as to obtain a first set of image data having a first dynamic range;

without resetting said pixels, after a second predetermined period of time reading a second output from each said pixel so as to obtain a second set of image data having a second dynamic range; and

combining said first and second sets of image data in order to obtain a resultant set of image data having a further dynamic range different from said first and second dynamic ranges.

Preferably, the method further comprises, without resetting said pixels, after at least a third predetermined period of time reading at least a third output from each said pixel so as to obtain a third set of image data having a third dynamic range; and

combining at least said first, second and third sets of image data in order to obtain a resultant set of image data having a further dynamic range different from said first, second and third dynamic ranges.

In accordance with a second aspect of the invention, there is provided a method of operating a solid state image sensor having an image sensing array comprising a plurality of active pixels, the method comprising:

resetting and immediately reading a preliminary output from each said pixel;

after a first predetermined period of time, reading a first output from each said pixel.

Preferably, the method further includes the step of determining the difference between said preliminary and first outputs so as to obtain a set of image data substantially free of noise components represented by said preliminary outputs.

Preferably, the method in accordance with the first aspect of the invention is combined with the method in accordance with the second aspect of the invention, wherein said preliminary outputs of the second aspect are read immediately after performing the resetting step of the first aspect.

Preferably, the method further includes the step of determining the difference between said preliminary outputs and each of said first, second and any subsequent outputs so as to obtain a plurality of said sets of image data each of which is substantially free of noise components represented by said preliminary outputs.

Preferably, in each of the aforementioned aspects of the invention, the or each said predetermined time period is selected to be an integer multiple of a predetermined lighting flicker period.

Preferably, in each of the aforementioned aspects of the invention, said image sensing array remains continuously exposed to incident light while the method is performed.

In accordance with a further aspect of the invention, there is provided a solid state image sensor adapted to perform a method in accordance with any one of the first to third aspects of the invention.
In accordance with another aspect of the invention, there is provided a solid state image sensor system

adapted to perform a method in accordance with any one of the first to third aspects of the invention.

In accordance with still another aspect of the invention, there is provided a camera incorporating a solid state image sensor or image sensor system adapted to perform a method in accordance with any one of the first to third aspects of the invention.

US-A-5926214 discloses image sensors and methods of operation thereof wherein multiple read cycles are performed between resets of an active pixel sensor array. However, these methods are concerned only with noise reduction and require the use of an optical shutter to mask the array from incident light during an initial reset/read cycle and during subsequent read operations between successive integration periods.

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figs. 1(a), 1(b) and 1(c) illustrate, respectively, a passive type image sensor pixel, a 3-transistor active image sensor pixel and a 4-transistor active image pixel; and

Fig. 2 illustrates a portion of one example of a 3-transistor active pixel image sensor array.

Referring now to Fig. 2 of the drawings, a 2x2 pixel portion of a typical active pixel CMOS image sensor array 1 is shown. The array 1 comprises a plurality of rows 3, 5… and columns 4, 6… of active photosensitive pixels 10 defining an image sensing area. The pixels may be addressed sequentially by vertical 12 and horizontal 14 shift registers electronically connected to the pixels as shown, or by any other suitable pixel addressing scheme such as a decoded address scheme. The shift registers 12, 14 are electronically connected to scanning circuitry (not shown) for scanning - i.e. reading - the pixel outputs to an output O/P. Any of a variety of known types of active pixel may be used for the pixels of the array. In the array of Fig. 2, the pixels 10 each comprise a photodiode 11 and associated transistor circuitry for use in amplifying (buffering) the diode outputs and for reading and resetting the diodes 11, as is well known in the art.

In conventional use of a sensor array of this type, the pixels would normally be reset and light would impinge on the photodiodes 11 for a predetermined period (the integration period), before the pixels are read in order to capture a set of image data from the array. The pixels would then be reset prior to each integration period for each image to be captured.

In accordance with the present invention, multiple reads are performed between successive resets, as follows.

Firstly, the pixels are reset, destroying any previous pixel signals and forcing the photodiode of each pixel to a known reset voltage (V_{rt}), and are read immediately after being reset (preliminary read cycle or Read 0). It will be understood that, as in conventional image sensor operation, lines (rows or columns) of pixels are reset and read sequentially, so that all of the pixels in one line are reset simultaneously and then read simultaneously. However, this preliminary read cycle is performed immediately after resetting the pixels, rather than after a predetermined integration period as in conventional image sensors.

The output from each pixel when read immediately after reset is:

$$Out_0 = V_{rt} + N_{rst} + V_{off} + V_{img}$$

Where V_{rt} is the reset voltage (described above), N_{rst} is the reset noise (described above and different on each reset occasion), V_{off} is a circuit-induced voltage offset whose value can be unique to each pixel due to local random threshold variations, V_{img} is a signal due to any stray light integration which may have occurred between reset and Read 0. That is, Out_0 comprises a "dark" signal which contains noise

comprising the above mentioned components. However, these noise components remain substantially constant over short periods of time and until a new reset occurs.

Following Read 0, without resetting the pixels, light is integrated during a first predetermined integration period, T_{int1}, producing a signal, Sig_1, within each pixel due to the discharge of pixel capacitance by way of photo-induced leakage current. A first read cycle, Read 1, is performed at the end of T_{int1}. The output from each pixel when read at the end of T_{int1} is:

$$Out_1 = V_{rt} + N_{rst} + V_{off} + V_{img} + Sig_1.$$

By calculating the difference between Out_0 and Out_1, the value of Sig_1 can be determined free of the noise components which comprise Out_0, since these components are constant between Read 1 and Read 2; i.e.

$$Out_1 - Out_0 = Sig_1.$$

The read process described thus far therefore provides an output signal which is substantially free of noise.

Preferably, at least one further read cycle, Read 2, is performed after a second predetermined integration period, T_{int2}, again without resetting the pixels,

resulting in further discharge of the photodiode capacitance and producing a further signal, Sig_2, such that

$$Out_2 - Out_1 = Sig_2;$$

and

$$Out_2 - Out_0 = Sig_3;$$

Where $Sig_3 = Sig_1 + Sig_2$ and where Sig_2 and Sig_3 are also substantially free of the noise components represented by Out_0.

It can be seen that Sig_1, Sig_2 and Sig_3 provide sets of image data with different exposure periods so that the sensor outputs obtained from the three read cycles provide three different representations of the same scene taken close together in time and having different dynamic ranges. Sig_1, corresponding to the shortest integration period, will contain most information from relatively bright image areas but is likely to be underexposed in relatively dim image areas, Sig_2 will provide an intermediate view and Sig_3 will contain most information from relatively dim image areas but is likely to be overexposed in relatively bright image areas. The three images may then be combined in order to obtain a composite image having a dynamic range wider than could be obtained by means of a single integration period.

The three images may be combined in any of a variety of ways. Generally speaking, the signals will be normalised so that the highest luminance values from the first (shortest exposure) image are scaled to the upper end of a predetermined range of output values, the lowest luminance values from the third (longest exposure) image are scaled to the lower end of the range of output values, and intermediate composite output values are determined by combining and/or scaling intermediate values from all three images.

The pixels may be reset following the final read cycle. It will be understood that the number of read cycles may vary between resets. The method may be implemented using a substantially conventional image sensor, with suitably adapted control software and/or firmware and/or hardware for controlling the timing of reset and read cycles, sufficient frame storage resources to store the multiple sets of data captured in each read cycle, and suitable image processing software and/or firmware and/or hardware for combining the image data as required. Obviously, the greater the number of read cycles the greater the overhead of frame storage and data processing.

It will be understood that the increased dynamic range obtained by means of multiple integration periods and read cycles may be usefully employed independently of the preliminary read cycle (Read 0) which allows the cancellation of noise from the images. However, it is preferred that these

operations are combined in order to obtain images having low noise and wide dynamic range.

All of the images obtained by means of such multiple read cycles may be free of lighting flicker effects if the integration periods are each selected to be integer multiples of any lighting flicker period.

It will also be understood that the methods and image sensors of the present invention do not require the use of an optical shutter in order to mask the image sensor either during the initial reset/read operation or during subsequent read operations. Read 0 is performed immediately after reset, with resetting and reading being performed on a sequential, line-by-line basis, and subsequent reads are performed in a similar manner while integration continues.

The methods of the invention may be implemented by means of a suitably adapted image sensor, or image sensor system, or camera incorporating an image sensor or image sensor system. The methods are also applicable to any type of active pixel architecture, most suitably of the CMOS type, supporting non-destructive read operations. Additional examples of such pixel architectures are illustrated in US-A-5926214.

Improvements and modifications may be incorporated without departing from the scope of the invention as defined in the Claims appended hereto.

Claims

1. A method of operating a solid state image sensor having an image sensing array comprising a plurality of active pixels, the method comprising:

resetting each said pixel;

after a first predetermined period of time reading a first output from each said pixel so as to obtain a first set of image data having a first dynamic range;

without resetting said pixels, after a second predetermined period of time reading a second output from each said pixel so as to obtain a second set of image data having a second dynamic range; and

combining said first and second sets of image data in order to obtain a resultant set of image data having a further dynamic range different from said first and second dynamic ranges.

2. A method as claimed in Claim 1, further comprising, without resetting said pixels, after at least a third predetermined period of time reading at least a third output from each said pixel so as to obtain a third set of image data having a third dynamic range; and

combining at least said first, second and third sets of image data in order to obtain a resultant set of image data having a further dynamic range different from said first, second and third dynamic ranges.

3. A method of operating a solid state image sensor having an image sensing array comprising a plurality of active pixels, the method comprising:

resetting and immediately reading a preliminary output from each said pixel;

after a first predetermined period of time, reading a first output from each said pixel.

4. A method as claimed in Claim 3, further including the step of determining the difference between said preliminary and first outputs so as to obtain a set of image data substantially free of noise components represented by said preliminary outputs.

5. A method as claimed in Claim 1 or Claim 2, in combination with a method as claimed in Claim 3 or Claim 4, wherein said preliminary outputs of Claim 3 or Claim 4 are read immediately after performing the resetting step of Claim 1 or Claim 2.

6. A method as claimed in Claim 5, further including the step of determining the difference between said preliminary outputs and each of said first, second and any subsequent outputs so as to obtain a plurality of said sets of image data each of which is substantially free of noise components represented by said preliminary outputs.

7. A method as claimed in any preceding Claim, wherein the or each said predetermined time period is selected to be an integer multiple of a predetermined lighting flicker period.

8. A method as claimed in any preceding Claim, wherein said image sensing array remains continuously exposed to incident light while the method is performed.

9. A solid state image sensor adapted to perform a method as claimed in any one of Claims 1 to 8.

10. A solid state image sensor system adapted to perform a method as claimed in any one of Claims 1 to 8.

11. A camera incorporating a solid state image sensor or image sensor system adapted to perform a method as claimed in any one of Claims 1 to 8.

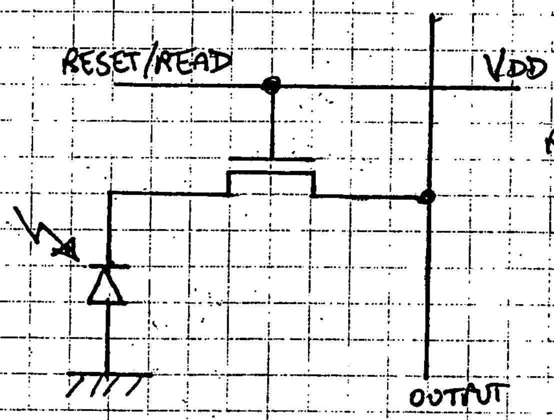


FIG. 1(a)

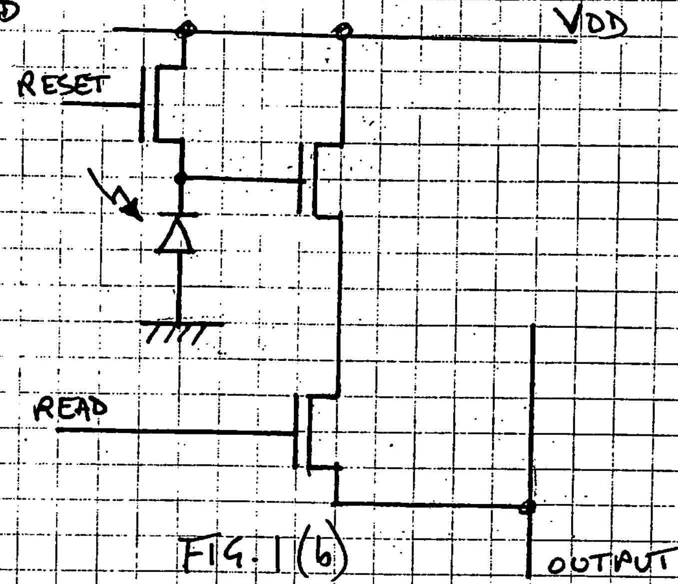


FIG. 1(b)

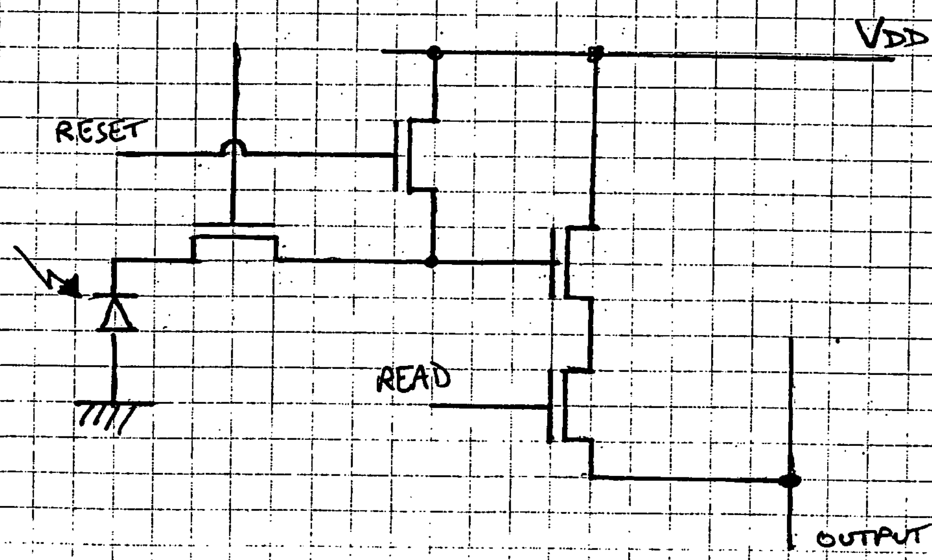
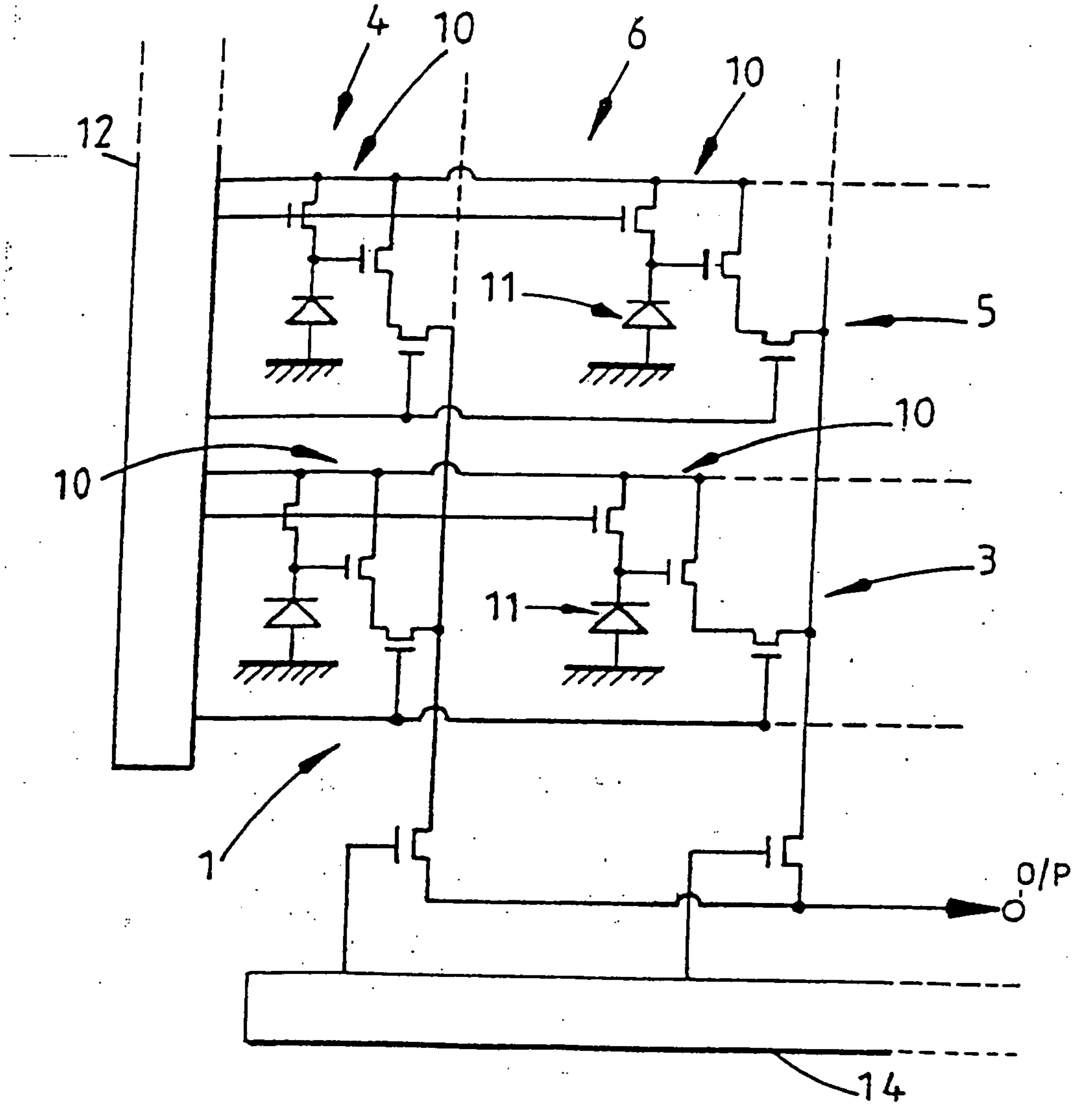


FIG. 1(c)



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